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A Study on Safety by Risk Assessment of Clean Room

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Abstract

This study analyze Clean Room accidents, Clean Room design main standard. Also, obtains various results from Heat & Smoke Simulation of analysis. The results are the smoke diffusion is quick with the effect due to a HVAC(Heating Ventilation and Air Conditioning) systems come to be quick, the possibility of getting the result and the possibility the role of the Sprinkler systems to reduce the diffusion of the smoke. We learn about the important to stop operation HVAC systems and to operate the Sprinkler system for securing safety by a fire detector.

1. Introduction

In order to improve the ratio and capacity of the state of the art product to the future of Scientific industry, a modern industry is increasing Clean Room facilities for advancement, preciseness and purity and sterile tendency. Clean Room is also demanding the expansive fields in semiconductor industry, electronic industry, information, communication industry, optical science machine, space aviation, hospital, laboratory, medical industry, food industry and etc. Many countries are confronting bad environments of the fire protection manuals about Clean Room around the world including America, Japan, Taiwan as well as our country.

The Clean Room which is the research object which it is the about 2,500 ㎡ with is the HVAC systems which has the pressure which above 30% is higher outside than and Top-Down method the high wind. Also, the Clean Room is composed with only the HVAC systems which relates in pure degree, to emergency the HVAC systems should be linked with the detector and, it does not apply defective occurrence because of the product.

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2.Accidents of analysis

2.1 Domestics accidents of analysis

Domestic Clean Room main accidents of process was special gas (SiH_4, AsH_3, PH_3, etc.) process, others gas (nitrogen,

hydrogen) process, acids process, organic solvent process, others process.

Table 1. shows domestic Clean Room main accidents.

Table 1. Example of domestic accidents

Time	Cause	Damage
1992. 5	▪ The exhaust duct didn't endured load because acid, alkali reactants were produced acid exhaust divergence piping inside. So, facility became down by it was happens crack and exhaust static pressure drop	▪ Lower part H-Beam corrosion as well as External PVC duct damage by acid exhaust duct was blocked
1999. 10	▪ Worker opened to fitting because was mistaken acknowledgment SiH_4 piping to other pipe. So, fire was occurred by SiH_4 spontaneous combustion	▪ There was no damage intercepting SiH_4 supply immediately
2000. 7	▪ Semiconductor equipment of Vent Line PVC pipe was occurred to explosion	▪ It were damaged that Semiconductor equipment and Scrubber
2001.	▪ Bellows type pipe of operating Mini Scrubber suction in Plenum area was occurred to fire by spontaneous combustion because SiH_4 was replenished with process equipment stops reaction	▪ It were damaged that mini scrubber vacuum pumps, duct piping ▪ The process was stopped by accident
2001. 3	▪ Fire was occurred by red phosphorus was exposed in the atmosphere after reaction	▪ The process was stopped by accident
2001. 6	▪ When worker replaced gas bottle of gas cabinet, leaked out toxicity gas	▪ The process was stopped because of worker evacuation
2002.	▪ Fire was occurred by electric leakage when using organic solvent in Wet Station	▪ There was no damaged by flame, but was damaged extremely by smoke

2.2 Outside accidents of analysis

Table 2. shows Outside Clean Room main accidents.

Table 2. Example of outside accidents

Time	Cause	Damage
1982. (Japan)	▪ Fire was occurred by exhaust gas powder of accumulation	▪ The process was stopped for 24 hours by exhaust duct damage and equipment of shutdown
1992. (Japan)	▪ Fire was occurred in exhaust duct bend	▪ It damaged fan and exhaust duct by fire
1996. 10 (Taiwan)	▪ It was exploded by hydrogen leakage of hydrogen gas storing	▪ It damaged $ 2,660,000 by fire
1997. 10 (Taiwan)	▪ Fire was occurred after branch duct(quality of the material Polypropylene) of fume duct new establishment	▪ Whole plant was damaged
1999. (Taiwan)	▪ Fire was occurred by an electric leak	▪ Smoke was diffusion in Fab area because of no dedicated exhaust systems
2000. (Japan)	▪ Gas was leaked by employee was opening valve differing through a mistake during work	▪ The six employees was poisoned by gas
2001. (Japan)	▪ Fire was occurred when using organic solvent in Wet Station	▪ Smoke was removed about sixty hour ▪ The production was discontinued for five days

2.3 Domestic & Outsides accidents analysis result

We learned more damage by smoke than damage by flame in fire, because it was special facilities of Clean Room that keep high-quality equipment and device, and given cleanliness. Specially, It will be suffer huge damage by slight accidents because semiconductor industry is major industry in our country

It is stored poisonous, pyrophoric, combustibility, flammability chemical substance in Clean Room, workers are late evacuation in fire because of wearing dustproof clothes.

So, Clean Room causes larger size accident than accident of general productive facility.

3. Clean Room design main standard comparison & analysis

In 1999, a step was proceeded in uniformity of universal standard because ISO 14644 international standard about cleanliness was announced. But, was explained about standard only method to manage cleanliness and standard of HVAC systems.

NFPA Code and FM (Factory Mutual Property Loss Prevention Data Sheets), IRI (Industrial Risk Insurers) of fire insurance company are explained about security standard of Clean Room.

It don't exist regulation about Clean Room because Domestic of law about Clean Room included factory in industrial facilities and research facilities, and Domestic of the Fire Services Act are applied Clean Room like general building. Only, there is Clean Room fire prevention standard that base on FM, IRI, NFPA Code connected with Clean Room in Insurance Association.

Table 3. shows Outside Clean Room design main standard comparison & analysis.

Table 3. Outside Clean Room design main standard comparison & analysis

Standard about Clean Room fire endurance	
IRI	▪ Clean Room exposed from combustibles occupancies shall be protected by two-hours fire resistance-rated construction ▪ Door in Clean Room should be protected by three-hours fire door
NFPA Code	▪ Clean Room shall be separated from adjacent occupancies by one-hour fire resistance-rated construction
FM	▪ Clean Room should be separated from adjacent occupancies by one-hour fire resistance-rated construction
Standard about Clean Room building materials	
IRI	▪ Interior finishing materials of wall, floor, ceiling should be approved non combustible material ▪ Structural material and inside finish should be minimized particle emission
NFPA Code	▪ Interior finishing materials of wall, floor, ceiling, partition shall be approved non combustible material
FM	▪ Interior finishing materials of wall, floor, ceiling should be approved non combustible material ▪ Where there are viewing windows provided in a Clean Room exterior wall, along an adjacent hallway is of noncombustible construction

Standard about Automatic Fire Extinguishing Systems	
IRI	▪ Sprinkler systems · Sprinkler system should be installed in building with Clean Room and in Plenum area · Sprinkler head should be installed on exhaust duct opening ▪ Fixed type Carbon Dioxide extinguishing systems should be installed in Wet Station inside and upside
NFPA Code	▪ Sprinkler systems · Automatic quick-response sprinklers shall be utilized for sprinkler installations within down-flow airstreams in Clean Room and Clean Zone ▪ Deluge Water Spray system shall be provided in the proximity of and directed at individual silane cylinders in silane dispensing areas
FM	▪ Sprinkler systems · Sprinkler system should be installed throughout all Clean Room regardless of classification · Sprinkler temperature rating should be 57℃ ▪ Fine Water Spray systems · Arrange Fine Water Spray system for automatic operation and for a minimum discharge time of 2 minutes ▪ Carbon Dioxide extinguishing systems · Design the Carbon Dioxide extinguishing system on a total flooding basis to achieve a minimum concentration of 50 percent within 1 minute in each compartment ▪ FM- 200 systems · Design the FM-200 system on a total flooding basis to achieve a minimum concentration of 7
Standard about Manual Fire Extinguishing Systems	
IRI	▪ Carbon Dioxide extinguisher should be installed in Clean Room ▪ Fire Hydrant system · Fire Hydrant hose station should be installed outside Clean Room
FM	▪ Carbon Dioxide extinguisher should be installed in Clean Room ▪ Fire Hydrant system · Hose station using hose with combination spray/stream nozzles should be provided near the doors of the Clean Room so that all points within the room are within reach of a hose stream
Standard about Detection & Alarm Systems	
IRI	▪ Air sampling type smoke detector should be installed for detect Plenum area whole of below access floor in Clean Room ▪Flame detector should be operated fixed type Carbon Dioxide extinguishing system by automatic interlock
NFPA Code	▪ Air sampling type smoke detector shall be provided in the Clean Room return airstream at a point before dilution from makeup air occurs ▪The discharge of an automatic fire suppression system shall activate an audible fire alarm system on the premises and an audible or visual alarm at a constantly attended location
FM	▪ Flame detector should be installed for detect Plenum area whole of below access floor in Clean Room. Also, it is considered to use air sampling type smoke detector or analogue type smoke detector

Standard about Fume Exhaust Systems	
IRI	▪ The duct should be constructed of noncombustible material ▪ Fume Exhaust Systems should be controlled all expected pollution materials by a minimum air velocity of 1m/s
NFPA Code	▪ Energy conservation devices that create a risk of returning contaminants to the Clean Room air supply shall not be used in fume exhaust systems ▪ The entire exhaust duct systems shall be self-contained. No portions of the building shall be used as an integral part of the systems
FM	▪ FMRC-Approved ducts should not be used for liquid removal ▪ Low point condensate drains should be provided where condensate may accumulate in ducts used for fume exhaust ▪ When fume exhaust systems are also used for smoke removal, should be designed to maintain a pressure of at least 50 Pa higher on the adjacent exposed areas than the fire area
Standard about Smoke Control Systems	
IRI	▪ The duct should be constructed of noncombustible material ▪ Smoke Control Systems should be designed to supply more than 1 ㎡ per 0.9 ㎥/min ▪ Smoke removal should be provided by dedicated smoke control systems arranged for automatic actuation by the smoke detection systems in the Fab area
FM	▪ Smoke removal should be provided by dedicated smoke control systems arranged for automatic actuation by the smoke detection system in the Fab area ▪ A secondary means of manual actuation of the smoke control systems should be provided in a clearly marked and accessible area outside the Clean Room ▪ The smoke control systems should be designed so that operational and functional tests can be done without interruption to the normal Clean Room air handling
Standard about Electrical Systems	
IRI	▪ Fume exhaust systems and smoke control systems should be installed emergency electric systems
FM	▪ The facility main substation should be fed from a minimum of two independent lines from separate utility substations ▪ UPS system should be provided for all main critical process safety controls
Standard about the others	
FM	▪ Scrubbers should not be located in the Clean Room or on the floors above the Clean Room ▪ For Scrubbers constructed of combustible material or containing combustible fill, sprinkler systems should be installed at the inlet and exhaust opening ▪ The noise level in a Clean Room should be maintained below 65dBs

4. Estimation safety by Heat & Smoke simulation

4.1 Form of HVAC systems in Clean Room

HVAC(Heating Ventilation and Air Conditioning) systems is controlled 20 ~ 600 times indoor air circulation per hour according to Class.

Table 4. shows division by HVAC systems in Clean Room.

Each Standards are explained about using emergence switch for intercept gas supply by smoke detector and gas leak detector, but it is not easy to use interlock actually. Because it is not less number of item of malfunction outbreak of detector, and suffers huge damage by stop of process.

Table 4.. Division by HVAC systems in Clean Room

Clean Room of method	Times air circulation per hour	Average wind velocity
Turbulence style of method	20~80 times/h	0.3~1.1m/s
AHU(Air Handling Unit) of method	350~450 times/h	0.3m/s
CTM(Clean Tunnel Module) of method	400~600 times/h	0.3m/s
Open Bay (Axial Fan) of method	400~600 times/h	0.3m/s
Open Bay(FFU : Fan Filter Unit) of method	400~600 times/h	0.3m/s

Fig. 1. shows air current in Clean Room. HVAC systems consisted to operate upper supply air, lower circulation

If smoke occurs, gas leaks, worker will get into danger more early time than general facility of worker.

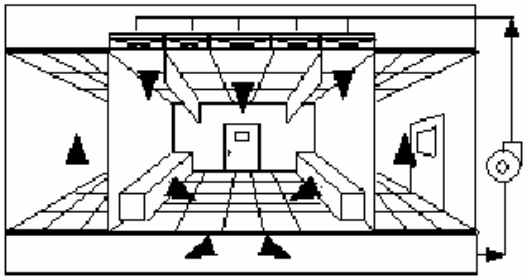


Fig. 1. Method of HVAC systems in Clean Room

4.2 Heat & Smoke simulation

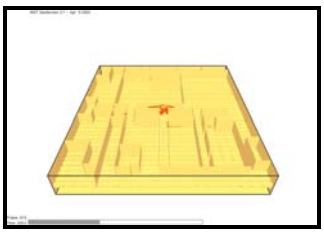
We apply FDS(Fire Dynamic Simulation) program of field model developed by NIST(National Institute of Standard and Technology), and suppose to enclosure fire envelope, no heat and mass transfer inside and outside in envelope, temperature of initial state of 20℃, to don't considered pressure by indoor uniform distribution, no initial flow, heat insulation condition of wall.

We apply fire growth as Ultra-Fast by using organic solvent in Wet Station, HRR(Heat Release Rate) as 3MW, uniformity of grid as 192,000 numbers.

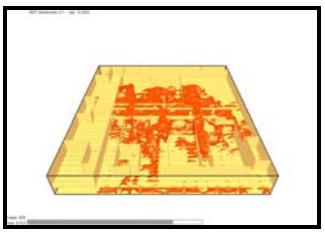
Like this condition, we perform Heat & Smoke simulation when HVAC systems operate, stop operation and as this condition HVAC systems stop operation, when sprinkler systems don't operate, operate.

4.2.1 When HVAC systems operate

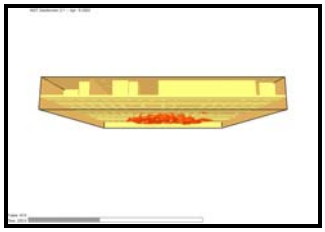
Wind velocity about upper supply air was applied average value measured each 4 times 5 times during 3 days chosen A area B area in Clean Room.



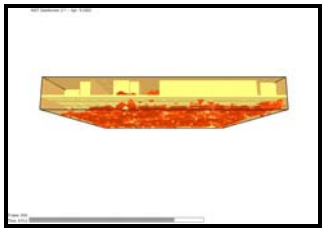
■ Smoke layer descent in Fab area (205s)



■ Smoke layer descent in Fab area (415s)



■ Smoke layer descent in Plenum area (205s)

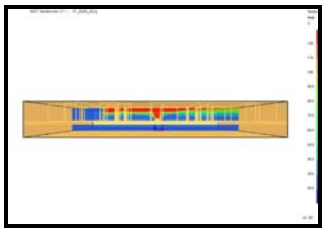


■ Smoke layer descent in Plenum area (415s)

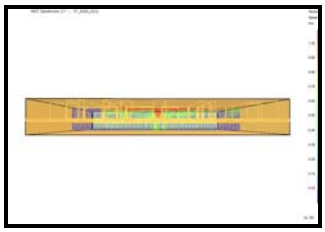
Fig. 2. Smoke simulation modeling when HVAC systems operate

Fab area and Plenum area are covered smoke within about 300s after fire because of dispersion by HVAC systems operate , and suffer huge damage.

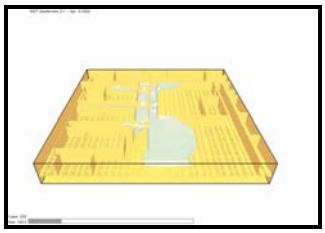
4.2.2 When HVAC systems stop operation



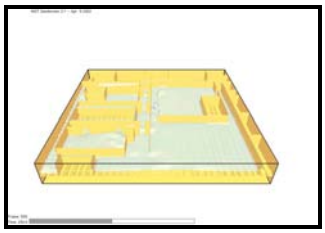
■ Temperature of distribution (240s)



■ Velocity of distribution (240s)



■ Smoke layer descent in Fab area (100s)



■ Smoke layer descent in Fab area (250s)

Fig. 3. Smoke simulation modeling when HVAC systems stop operation

In fire, we observe to spread toward ceiling smoke layer rising rapidly and to be different Clear Height by position change of seat of fire.

In result, we observe to passes over limit of evacuation condition of smoke layer Clear Height after 220s.

4.2.3 When sprinkler systems operate and didn't operate (as this condition HVAC systems stop operation)

■ Temperature of distribution when sprinkler systems didn't operate and operate (240s)

■ Velocity of distribution when sprinkler system didn't operate and operate (240s)

■ Smoke layer descent when sprinkler systems didn't operate and operate (300s)

Fig. 4. Heat & Smoke simulation modeling when sprinkler systems didn't operate and operate

4.3 Analysis result by Heat & Smoke simulation

4.3.1 Analysis result when HVAC systems operate and stop operation

1. In fire, smoke layer spread toward Fab area floor because of smoke layer dispersion by HVAC systems, also smoke layer spread toward lower Plenum area. Therefore, compartment is lost original usage by smoke layer spread toward the adjacent compartment Fab area because of irregular flowing smoke layer spread toward lower Plenum area.

2. In fire, we observe to spread smoke layer like general facility when HVAC systems stop operation

3. Therefore, in fire, HVAC systems should be stop operation, in fire.

4.3.2 Analysis result when sprinkler systems didn't operate and operate

1. We observe temperature of distribution are different about 40℃ because sprinkler systems serve to cool the smoke layer.

2. We observe velocity of vector are different about 0.2m/s because sprinkler systems serve to decrease size of flame.

3. We observe clear Height are different about 40s in Smoke layer descent because sprinkler systems serve to cool the smoke layer and to decrease size of flame.

5. Conclusions

1. Interior finish and duct should be constructed noncombustible material, and Clean Room should be separated from adjacent occupancies by one-hour fire resistance-rated construction.

2. Upon the detection of smoke, smoke control systems should be installed automatically to put the fire area under 100% exhaust and simultaneously to put the areas immediately adjacent to the fire area into 100% supply.

3. It is not less number of items of malfunction outbreak of detector, and suffers huge damage by stop process, but HVAC systems should be stopped automatically by smoke detector in fire.

Dedicated smoke control systems should be installed in Clean Room. So, Smoke removal should be provided by dedicated smoke control systems arranged for automatic actuation by the smoke detection system in the Fab area.

Therefore, we consider worker life safety preferentially, the next to reduced damage.

4. Sprinkler systems should be installed in Clean Room. While the downward force of the water discharge from sprinkler systems can lower the smoke level in Clean Room where a fire in burning, but sprinkler systems serve to cool the smoke and make it possible for worker to remain in the area much longer than they could if Clean Room are without sprinkler systems.

Reference

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